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Design for High Efficiency Fiber/Waveguide Power Coupler with SU8 Polymer

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Abstract

A method for designing a high efficiency SMF-28 fiber/waveguide power coupler comprised SU8 polymer is proposed and simulated numerically. Theoretically, the significant dissimilarity of the refractive index of a SMF-28 fiber and a SOI waveguide induces the dissimilitude of the mode field profile so that a low coupling efficiency for these two components comes out. In addition, bad alignment of fiber/waveguide interface in azimuthally and horizontal positions also elicits magnificent power coupling loss which is another reason for poor performance of coupler. In this study, we proposed an effective power coupler that consists of SU8 to substitute the silica to lessen the fiber/waveguide coupling loss. The proposed coupler with coupling efficiency of 76% is reachable.

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Keyword: *power coupler; SU8 polymer; mode field diameter; transmission efficiency*

1. Introduction

Photonic integrated circuits (PIC) have been proffered and progressed prosperously more than twenty years; the research current for realization of the PIC is to minimize the photonic devices to nano-scale. Silicon on insulator (SOI) waveguides [1-3] has merits of having great dissimilarity in index of refraction in the guided layer S_i as well as in the under guided layer (S_iO_2)/upper layer (air) so that a SOI waveguide has more compact mode profile enabling to attain PIC, but many predicaments for reaching higher coupling performance still exist and it is a hamper due to the narrow down of the component sizes. One of the

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problems needed to be overcome is to improvably optical power emitted from a laser source to a commercial single mode fiber (SMF-28 fiber with radius of 4μm) and then dispatched to a SOI rib single mode waveguide (with mode field diameter of 1~2μm).

There are some reported methods available to subdue the power coupling problems between fiber and waveguide interface. Methods of grating couplers [4] or inverted tapered couplers [5-7] to improve the coupling efficiency are generally impeded by the inadequate end-facet and the diverse mode field profiles between SMF fiber and SOI waveguide. Waveguide constructed by SU8 polymer [8-10] is an alternative candidate for raising the optical power while its coupling ability less than 39% is a reason of unpopularity.

In the study, we offered a new method to design a optical coupler and simulate it with BeamPROP software from *RSoft*. to demonstrate that the proffer method is feasible for gaining higher coupling efficiency. We design a tri-level layer converter (TLL) to have effectual optical power converting from a SMF-28 fiber to a SOI rib waveguide. Finally, the required extent for the TLL to reach the whole efficiency 76% is only 1960μm .

2. Design

Figure 1 illustrates the constituent parts of the proposed 3D SOI rib single-mode waveguide with the refractive indices of silicon ($n_1=3.476$) deposited upon silica S_iO_2 ($n_2=1.444$) substrate and the cover is air with the refractive index $n_3=1$ at the wavelength of λ=1550nm. The waveguide with rib region has the width w=1μm, the slab thickness s =0.358μm and the height H =0.838μm. Figure 2 exhibits the cross-section and the layer length for the top, the middle and the bottom layers with 980μm×6μm and L_0, 1470μm×2.14μm and L_1, 1960μm×0.82μm and L_2 , respectively.

Theoretically, the evaluation of the present TTL consists of four parts which are the coupling efficiency from a SMF-28 fiber to the enter facet of the TTL, the coupling efficiency from SU8 to silicon, the SU8 mode conversion efficiency and the silicon mode conversion efficiency. A 3D quasi-vectorial (quasi-TE) BPM [11] is employed for evaluating the performance.

Firstly, a quasi-TE mode power is inputted from a SMF-28 fiber to a 3D SOI rib waveguide with no design of TTL. One finds that the coupling loss is comparatively obvious with coupling efficiency of 25% because of the bad mode matching and alignment between the SMF-28 fiber and the SOI waveguide. On the basis of this motive , we design a bi-layer taper waveguide and try to reanalyze it to estimate the impact of the taper length of the bi-layer waveguide on the mode conversion efficiency; the simulation result illustrates the coupling efficiency for the bi-layer waveguide only reach 57% at waveguide length larger than 6950μm..

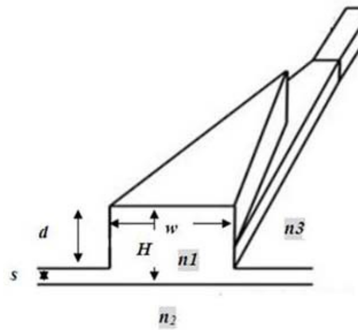

Fig. 1. The front-view diagram of waveguide structure under study, n_1, n_2 and n_3 are the refractive indices of the guided layer, the substrate and the cover region, respectively; H and w are the height and width of the rib region,s is the slab's thickness

In view of above mentioned reasons, we redesign a tri-level layer converter (TLL) comprised by silica material with all three layer widths w= 8μm for which it can well match with the diameter of SMF-28 fiber to obtain higher coupling power. We evaluate the designed TTL performance with BeamPROP by choosing the grid sizeΔx=0.01μm, Δy=0.01μm and Δz=0.1μm for numerical convergence. Numerical results show that the quasi-TE mode power strongly depends on the alignment of the SMF-28 fiber and TTL, the coupling conversion efficiency η=71% can be reached. From the results obtained with this design of TTL, we find that the top layer of TTL strongly dominates the mode conversion efficiency while the down layer of TTL is irrelevant to it. For this reason, we redesign a TTL by replacement of silica with SU8 polymer (n_{su8}=1.65 vs. n_{sio2}=1.444) for achieving better performance.

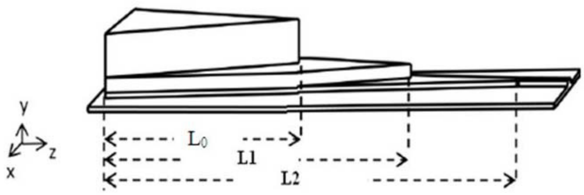

Fig.2 The side-view diagram of the tri-level layer converter (TLL)

3. Numerical Simulated results

In theoretical investigation, a longer waveguide is required for obtaining better optical power transmission from a SMF-28 fiber to a SOI single-mode waveguide and a slender width w of the top taper layer of the TTL is also demanded to guarantee all the power emitted from laser source to be glossily delivered to the top layer even transferred to the bottom layer of the TTL. Here, we consider the down taper layer length L_2=1000μm and then calculate the quasi-TE mode power with respect to various the top layer widths w of the TTL for the L_2 length variation. Figure 3 gives the quasi-TE mode power percentage verse the top taper layer widths w for L_2 alteration. We find that the quasi-TE mode power was getting larger along with the length L_2 while this case is on the contrary with the top layer width w, the highest mode conversion efficiency η=90.5% can be approached at the top width 1μm<w<2μm.

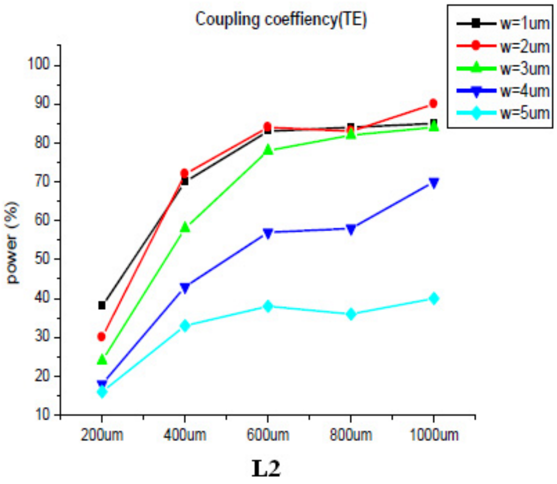

Fig. 3. The percent of the quasi-T E mode power as a function of bottom layer length L_2 for various top width *w* of the TTL.

Next, we study at what the middle layer length L_1 and the bottom layer length L_2 of the TTL affecting the quasi-TE power coupling efficiency, the simulation results for the quasi-TE mode power verse the different values of L_1 and L_2 are depicted in Fig. 4. It can be seen that as the length L_1 of the middle layer is longer than 800μm, the quasi-TE mode power grows while the mode power has nothing to do with the bottom layer length L_2 of the bottom layer. In summary, the achievable quasi-TE mode coupling efficiencyη=76% is at the length of L_1+L_2=1960μm.

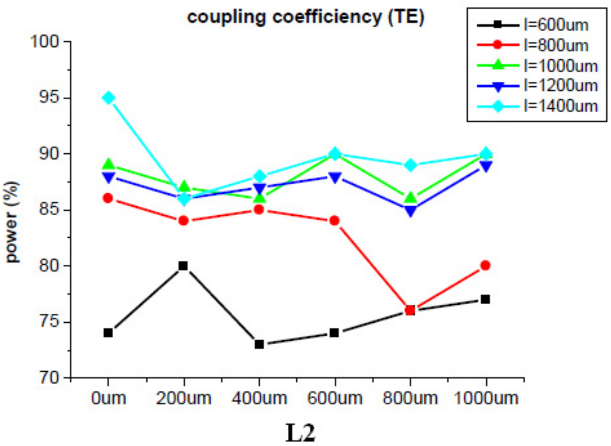

Fig. 4. The percentage of the quasi-TE mode power as a function of bottom layer length L_2 for various middle layer length L_1

We hope that this proposed TTL is independent of the variation of the index of refraction of the silicon material. Fig. 5 shows a relationship of the percentage of the quasi-TE mode power verse the change of the refractive index of the guiding layer from $n_{si}=3.40$ to $n_{si}=3.60$. We find that the quasi-TE mode power of the proposed TTL keeps immune to the refractive index variation of the guiding layer, it is confirmed again that the proposed TTL has the potential in wider fabrication tolerance with CMOS process technology.

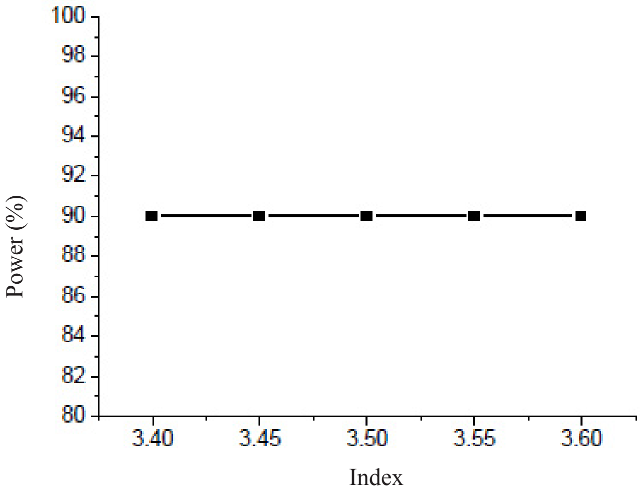

Fig. 5. the percentage of the quasi-TE mode power as a function of the refractive index variation.

4. Conclusion

A TTL with the capability of higher quasi-TE mode power conversion performance and wider refractive index insensitivity has been designed and simulated in this work. A SU8 employed to substitute silica in the TTL as a substrate layer provides well matched of the mode field profile between SMF-28 and SOI waveguide. Additionally, the optimal design of each taper layer of the proposed TTL also give the help for meliorating the mode conversion efficiency. Calnulated results exhibit that the mode coupling efficiencyη=76% is obtainable.

Acknowledgements

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